SPECIAL ARTICLE

Other faces in the mirror: a perspective on schizophrenia

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A patient with schizophrenia may generate an action (whether manual or verbal), but not attribute the generation of that action to himself. We distinguish self-monitoring and attribution of agency, relating only the former to forward models and the mirror system. We suggest that alien hand experiences occur when an action progresses through hand control pathways with no record of disinhibition having been kept and is then seen but dismissed as external. Analogously, auditory pathways are active during verbal hallucinations and produce a subvocal verbal process, but since no record is kept of the words being created, they are treated as external. The subject then proceeds to confabulate, to provide an account for the agency.

Key words: Schizophrenia, mirror systems, self-monitoring, attribution of agency, delusions

(World Psychiatry 2007;6:75-78)

The system of the monkey brain for visuomotor control of hand movements has its premotor outpost in an area called F5. This area contains a set of neurons, *mirror neurons*, with the property that each one is active not only when the monkey executes a specific grasp, but also when the monkey observes a human or other monkey execute a more-or-less similar grasp (1). Most writers have noted the adaptive advantage that such a system could have for social interaction, allowing one monkey to "understand" the actions of another, and thus position himself to compete or cooperate more effectively. However, monkey neurophysiology to date shows only that a macaque can "recognize" certain manual and oro-facial actions made by others, in the very special sense that the neural pattern elicited in the F5 mirror neurons by observing those actions is similar to that generated when he performs a similar action himself.

The mirror neuron system model (2) analyzes F5 mirror neurons as part of a larger mirror system, including parts of the superior temporal sulcus (STS) and area 7b of the parietal lobe. Observation of self-generated actions prepares the F5 mirror neurons to respond to hand-object relational trajectories even when the hand is of the "other", because the system processes the movement of a hand relative to the object, not the retinal input, which can differ greatly between observation of self and other. The system can categorize different actions (e.g., precision pinch vs. power grasp), but says nothing about the "binding" of the action to the agent of that action.

The region of the human brain homologous to macaque F5 is Brodmann's area 44 (3), part of Broca's area. This was traditionally thought of as a speech area, but has been shown by brain imaging studies to be active when humans both execute and observe grasps. These findings are the basis for one account of how the human brain changed from, but built upon, that of ancestral primates to make humans "language-ready". This is the "mirror system hypothesis": "The parity requirement for language in humans – that what counts for the speaker must count approximately the same for the hearer – is met because Broca's area evolved atop the mirror system for grasping with its capacity to generate and recognize a set of actions" (4). A brain that can support language needs not be one that evolved for this purpose, any more than our brains evolved under the pressure to ensure success at Web surfing (5). Specifically, the first hominids to have language-ready brains may have had limited protosign and protospeech, but no full language in the sense of a symbol system equipped with a rich syntax that supports a compositional semantics.

A number of papers (4,6-8) have related mirror neurons to internal models. Consider a system that combines circuitry in the brain encoding commands for a motor control task with the musculoskeletal machinery executing the task as well as with the perceptual machinery generating a neural code for the resultant interaction of the body with the external world.

A *forward model* for such a control system computes the neural transformation Command ➛ Response within the brain to provide an expectation of how the current action will turn out – and thus a basis for correcting for unexpected deviations. It is activated by a corollary discharge of the command to the motor system. Conversely, an *inverse model* provides a neural computation of the map Response ➛ Command, and is thus useful in planning how to obtain a desired response.

The mirror system hypothesis suggests that mechanisms similar to those for generating manual actions – with each control system linked to a forward and inverse model – are available for the phonological component of language, with different control systems and paired models for different sound patterns. However (9,10), the action and mirror system for the sound of a word is distinct from, though intimately linked to, the system for understanding the meaning of the word and mechanisms for generating and comprehending sentences.

AGENCY AND SCHIZOPHRENIA

How do we as humans know the agency of actions? In particular, how does one discriminate one's actions from those of another person? If I am a normal adult, when I move my hand, I know I moved it and also know that someone else did not move it. The same goes for speech and thought. Yet, schizophrenic patients hallucinate voices that they attribute to external agents; they also have delusions that other people are causing movement of their bodies; and they also have delusions of influencing others to act (11,12). In addition, patients with schizophrenia have difficulty determining whether they spoke or thought an utterance (13,14).

To understand both what one is doing oneself and what other people are doing, one needs both a notion of *action*, what is being done, and of *agency*, who is doing it. It has been argued that the brain's mirror systems give humans and many other animals a way of placing themselves in the actions of others. In this paradigm, a mirror system supports my ability to imagine myself moving my hands or saying something in the way another person does while I observe that person executing his actions. However, to function effectively, my brain must *in addition* correctly "bind" the various actions to the appropriate agents.

The binding for actions that I make, or actions that are directed to me, may involve processes partially separate from those involved in binding of actions to other agents. An example might be the observation that delusions in schizophrenia seem to be directed at the patient, or from the patient to another actor. If all agents, including the self, were created equal, we would expect that schizophrenics would experience as many third person delusions (actor to actor) as first person delusions (actor to self/self to actor).

Frith (15) offers another view of binding which must not be confused with the binding of action to agent. He starts from experiments of Haggard et al (16) in which subjects are asked to indicate the time at which they initiated an action. When the subject's button press causes an event, the times of action and event are perceived as being closer together than they actually were. However, when an involuntary movement (caused by transcranial magnetic stimulation) is followed by a tone, then the action and the event are perceived as being further apart in time. Frith thus argues that what he calls *intentional binding*, in which the cause and its effect are perceived closer together in time, could be an indicator of self-agency. The flaw in this argument is that, if the subject is unaware of causing the action, he may not monitor the timing of the cause in a way that grounds this judgment.

Impairment of self-monitoring

Daprati et al (17) had subjects perform a requested movement with the right hand while monitoring an image of a hand movement – either a display of the subject's own movement, or a movement started by the experimenter at the same time and from the identical initial position (see 18 for a related study). Once the movement was performed and the screen had blanked out, the subject was asked to answer "yes" if he saw his own hand performing the movement but answer "no" otherwise. One of three possible images could be presented to the subject in each trial: his own hand; the experimenter's hand performing a different movement, or the experimenter's hand performing the same type of movement. Both normals and schizophrenics made virtually no errors except in the last condition, where the median error rate was 5% in the control group, 17% in the non-delusional group and 23% in the delusional group.

However, *the experiment has little to do with attribution of agency*. In each case, the subject knows that he has made a movement and which type of movement it is – it is just a case of monitoring that movement accurately enough to tell whether a slight variant is indeed different. To clarify this, Mundhenk and I (19) distinguished two *different* factors that may affect the symptoms of schizophrenia: *self-monitoring*, which involves maintaining a working memory of one's recent actions as a basis for evaluating their consequences, and *attribution of agency*. The claim, then, is that the experiments of Daprati et al show impairment of self-monitoring, not attribution of agency.

Note that this function of self-monitoring is exactly that ascribed to a forward model. The model creates expectations which allow one to judge whether the ongoing action is indeed proceeding in the intended way. Frith (15) reviews the considerable work that he and his colleagues have conducted (e.g., 20,21) to advance the view that delusions of alien control are associated with abnormalities in the forward model's prediction of the outcome of intended actions. However, as Frith himself notes, some patients with lesions of supplementary motor area (SMA) or anterior corpus callosum exhibit a condition called anarchic hand (22), where the contralesional hand performs actions that the patient did not intend – yet the patient usually reports that there is something wrong with his hand, not that it is being controlled by alien forces. This is further evidence that imperfect self-monitoring is distinct from erroneous attribution of agency.

Frith also provides an accessible overview of literature that complements that discussed here. Other reviews relevant to the present discussion focus on the "social brain" (23) and on "theory of mind" (24). In relation to both these topics, a number of authors have suggested that the role of the mirror system in understanding manual, vocal and orofacial actions extends to support understanding and empathizing with the actions of others (25,26).

Attribution of agency

As Frith (15) notes, a touch we apply to ourselves feels

less intense than the same touch applied by someone else, but patients experiencing delusions of control do not show this attenuation (21). This suggests that corollary discharge does not automatically accompany the prefrontal signal to the motor system. Instead, I hypothesize that the forward model can only be activated by a "willful command" – that when one commits oneself to a movement, one both activates the forward model (grounding self-monitoring) *and* stores the intention of the action in working memory (attribution of agency to the self).

While several authors, as we have seen, suggested a role for extended mirror systems in recognizing the action of others, less attention has been given to the mechanisms whereby the brain can distinguish the "simulation" involved in recognizing the action of another from the actual creation of an action by the self. We do not, generally, attribute agency to movements of a disembodied hand. Rather, we seek to link the hand to a person whose face we can recognize. The binding of agent (whether self or a particular other) to action in working memory plays a crucial role in our behavior and our understanding of behavior.

Note that departure of an action from my expectation (forward model) for that action needs not call my agency into account. For example, if I suddenly swerve while driving, I will not have intended that swerve in advance but will recognize that it was an appropriate (but not premeditated) response to, say, an unexpected obstacle and that it fits within my overall intention.

Although the two processes are separate, self-monitoring may be crucial to my understanding of my agency with respect to certain observed consequences. In the case of a swerving car, I may compare a trajectory with an expected trajectory to decide (consciously or unconsciously) whether the departure was such that I should posit an external cause. But in either case, I know that I am the agent of my primary action, even if it departs from my expectations. Moreover, my brain can take account of feedback both at and below the conscious level of my intentions. For example, when I speak I may be most conscious of feedback on the effect of my communicative intention, yet I am constantly making adjustments at many levels down to the detailed effects of articulation.

In summary, the issuing of any command for action within the brain is accompanied by an expectation of the outcome of that action, and current actions generally unfold within the context of recent actions and ongoing plans which situate potential future actions with respect to current goals. Goals, plans, intentions, actions and expectations all require "working memories", whether the data they contain are accessible to conscious introspection or not.

Back to the delusions of schizophrenia

We may say that an action *m* is intended only if there is explicit prefrontal activity *x* to prime it, and other prefrontal activity *y* to release the inhibition that holds its premotor activity below the threshold for execution.

Arbib and Mundhenk (19) hypothesize, then, that each action is accompanied by a more or less accurate motor working memory of the trajectory of the action. Thus, if the need arises to question the agency of the action, the brain may consult its working memories (the plural is significant) to determine whether there was the *x,y* of priming and disinhibition prior to the action and, if so, whether the working memory of expected outcome of the action sufficiently matches the observed trajectory of the outcome. On this basis, the normal brain can decide "I am the agent", "I was the agent but for some reason the action did not come out as intended", or "I am not the agent".

We relate this to schizophrenia by hypothesizing that the primary deficit is in the lack of adequate control of inhibition. If the brain cannot maintain inhibition at an adequate level to block unintended actions, then an action may be made without need for a disinhibitory signal *y* that represents the decision to execute the action. Lacking any memory of having intended the action, the patient concludes "I am not the agent" and then proceeds to confabulate, to provide an account for the agency of the observed action.

Schizophrenic misattributions of agency are commonly linked to hand movements and language. While delusions of influence are not as common as auditory verbal hallucinations, in most cases they take the form that the schizophrenic hallucinates that another agent is causing his hand to move. This leads us to stress the relevance of the mirror system hypothesis for the study of schizophrenia. Extending the hypothesis, we suggest that the working memories for language production are evolved from, yet still closely related to, those for hand movements. This would explain why the disease does not strike all working memories and all "releasers of intention" equally, but most affects those for hand movements and language.

We suggest that schizophrenia is a disorder of the combined system, but also stress that the disorder leads to an impairment of this working memory system that is statistical in effect, rather than simply excising the whole system. Thus, depending on "where the dice fall", the patient's misattribution of agency may be related more to hands or voices, or may affect both in large part. We thus suggest that auditory verbal hallucinations are accounted for by the observation that auditory pathways are active during hallucinations (27) and produce a verbal process of some internal voice, but, since no record is kept of the voice being created, that voice is treated as external. That is, an utterance is created and progresses through verbal creation pathways, and returns as a vocalization *observed*, only to be dismissed as external, since no record of it being created has been kept. Schizophrenic patients, on this account, then confabulate the agent. The confabulated agent then takes on a strong identity persisting across hallucinatory episodes, even if the fictitious agent is nowhere to be found, or does not even exist.

Acknowledgement

The author would like to thank Nathan Mundhenk for his contribution to the mirror system analysis of schizophrenia (19) which formed the basis for much of this article.

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